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A scenario process to inform Australian geoengineering policy

Anita Talberg[a,b,c,*], Sebastian Thomas[a,b,d], John Wiseman[a,e]

[a] Australian-German Climate and Energy College, University of Melbourne, Victoria, 3010, Australia
[b] Sustainability Science Lab, University of Melbourne, Victoria, 3010, Australia
[c] School of Earth Sciences, University of Melbourne, Victoria, 3010, Australia
[d] School of Ecosystem and Forest Sciences, University of Melbourne, Victoria, 3010, Australia
[e] Melbourne Sustainable Society Institute, University of Melbourne, Victoria, 3010, Australia

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ABSTRACT

Geoengineering is a high-stakes policy issue that calls for research and debate that is pluralistic, reflexive and socially accountable. This paper reflects on an Australian geoengineering scenario project as a practical and innovative platform for informing governance. We produce multi-scale scenarios—representing Australia and the world— built on four fundamentally different archetypes, in which three include geoengineering. According to the four scenarios: greenhouse gas emissions continue increasing to 2050 but not long beyond; except with accelerated technology development and adoption, climate change impacts by 2050 become globally relevant; the risk of unilateral geoengineering deployment without adequate governance is low; and the framing of geoengineering deployment can be characterized as either climate mitigation, adaptation or optimization. Australia's role in geoengineering can be described as passive in the global context, but Australia can benefit from an early transition to a low-carbon economy. A review of the evolution of ideas throughout the exercise reveals a process of shared learning that helps to focus governance discussions around key issues. This study is one step towards increasing the presence and influence of the Asia-Pacific in geoengineering discussions, and highlights the value that a tailored scenario exercise can bring to governance discussions.

1. Introduction

Geoengineering refers to a collection of proposed methods for adjusting the Earth's energy balance to moderate global warming. It is usually held to include carbon dioxide removal (CDR) techniques and solar radiation management (SRM) methods (Royal Society, 2009). The former aim to extract greenhouse gases from the atmosphere for semi-permanent storage in biomass, underground or in the deep seabed. Mostly, these methods are technically feasible (National Research Council, 2015a) but are slow-acting, costly, and have limited capacity to moderate warming (Lenton, 2014). In contrast, SRM methods, which aim to intercept incoming solar energy before it reaches the Earth, are considered fast-acting and relatively cost-effective—although there are conflicting views on costs (Goes, Tuana, & Keller, 2011)—but risky. Modelling suggests that SRM methods could alter local temperature profiles, rainfall patterns and weather systems in uneven ways, leading to a series of social and environmental challenges (National Research Council, 2015b).

Many geoengineering proposals interact directly with marine or atmospheric environments, such that their effects cannot be confined to national borders. Although some international treaties, such as the Convention on Biological Diversity and the London Convention, have discussed and, in some cases, ruled on elements of how to govern certain geoengineering research, there are

* Corresponding author.
E-mail address: anita.talberg@unimelb.edu.au (A. Talberg).

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currently no international laws formally and explicitly regulating geoengineering deployment. Instead, there exists a tension between two international legal norms—that of 'precaution' and that of 'harm minimization' (Talberg, Christoff, Thomas, & Karoly, 2017). Together these norms encapsulate the difficulty in managing an issue that is complex, has high stakes and is highly uncertain from both scientific and social perspectives. In short, geoengineering is novel and risky and its implications are potentially significant; it is thus a policy issue of extreme importance.

How do we make decisions about something that we do not fully understand, yet could (at its extremes) create either an existential crisis or solution for the planet? A traditional approach might treat it as "a mission-oriented project similar to the Manhattan Project" (Somerville, 2006, p. 1277), that would be "designed, funded, and managed by federal agencies to achieve a specific technological solution for which the government was effectively the sole "customer"" (Mowery, Nelson, & Martin, 2010, p. 1012). Yet, the nature of geoengineering as a complex issue with contested political, cultural, moral, scientific and economic values, calls for 'post-normal' (Funtowicz & Ravetz, 2003) policy-relevant research that is applied, transdisciplinary, heterogeneous, reflexive, socially accountable, and has a broad set of quality control criteria (Hessels & van Lente, 2008).

The geoengineering governance debate is largely driven by academic communities (Talberg et al., 2017). Proposals on how geoengineering could be governed have been developed by scholars from across multiple disciplines, including law (Ginzky, 2010; Lin, 2009; Markus & Ginzky, 2012; Parson & Ernst, 2013; Reynolds, 2015), philosophy (Morrow, Kopp, & Oppenheimer, 2009), international relations (Victor, 2008; Virgoe, 2009), economics (Weitzman, 2015), and the natural sciences (Keith, 2017; Lloyd & Oppenheimer, 2014; Michaelson, 1998). Governance proposals put forward by these proponents and others—such as activists, think tanks, and government agencies (Bipartisan Policy Center, 2011; Energy Futures Forum, 2006; Umweltbundesamt, 2011)—are broad and varied but often share a common limitation: most do not include foresight processes. Yet much of the geoengineering research literature relies heavily on the use of scenarios (Talberg, Thomas, Christoff, & Karoly, 2018), and scenario approaches offer a practical and innovative response to the problem of geoengineering, creating platforms for iterative and "socially robust knowledge" production (Nowotny, 2003, p. 155).

Understanding of the value of scenario methodologies for improving geoengineering governance is still at an early stage. Governments, regulators and communities at local and national levels face increasingly complex social-ecological problems, which call on new "ways of knowing, learning, valuing and acting" (Kagan, 2012, p. 10), yet the key tools to facilitate this type of foresight informed public debate and deliberative governance (i.e. scenarios) are still underused in the policymaking context (Volkery & Ribeiro, 2009). The abundance of scenario-construction guides in the futures literature is plagued by a "methodological chaos" (Bradfield, Wright, Burt, Cairns, & van der Heijden, 2005). Democracy is more comfortable applying "techniques for selecting among well defined alternatives" than "looking for new skills for creating imaginative solutions" (Rayner et al., 2006, p. 12). This paper aims to contribute to understanding of the potential value of scenario methodologies for improving geoengineering governance by describing and reflecting on a recent Australian geoengineering scenario project.

A focus on Australia is justified by the relatively low level of engagement on geoengineering to date from both the Southern Hemisphere (Talberg et al., 2017) and the Asia Pacific region (Sugiyama et al., 2017). Australia is highly vulnerable to climate change (Reisinger et al., 2014), but also has favorable biogeophysical characteristics for hosting CDR or SRM trial projects. Australia has access to extensive land and ocean areas. The Southern Ocean has been shown to sequester carbon through natural iron fertilization (Lampitt et al., 2008), suggesting that it may be a suitable location for scientific marine geoengineering experimentation. Further, Australia's stable political and regulatory environment and its secure airports close to airspace in the Tropics provide ideal conditions for testing atmospheric SRM methods.

To increase the presence and influence of the Asia-Pacific in geoengineering discussions, Prantl (2011) specifically suggests that initial efforts might include "regional consultations, scenario-building, and public and civil society engagement." Our scenario exercise is one step in that direction.

2. Method

Our method is based on the Mānoa School Scenario Modeling Method of Dator (2009), which is built on the understanding that alternative futures can be categorized into four fundamentally different archetypes: Growth, Collapse, Discipline, and Transformation (Dator, Sweeney, & Yee, 2015); the features of which are outlined in Table 1. The future is likely to be some combination of elements from all four types, but by framing a scenario exercise around archetypical images of the futures, participants are forced outside their own worldviews. These archetypes, developed "[t]hrough years of empirical research" (Bezold, 2009, p. 136), expedite the inductive

Table 1
Characteristics of the archetype scenarios from the Mānoa School Scenario Modeling Method of Dator (2009).

	Growth	Collapse	Discipline	Transform
Population	Increasing	Declining	Diminished	Post-human
Energy	Sufficient	Scarce	Limited	Abundant
Economics	Dominant	Survival	Regulated	Trivial
Environment	Conquered	Overshot	Sustainable	Artificial
Culture	Dynamic	Stable	Focused	Complex
Technology	Accelerating	Stable	Restricted	Transformative
Governance	Corporate	Local	Strict	Direct

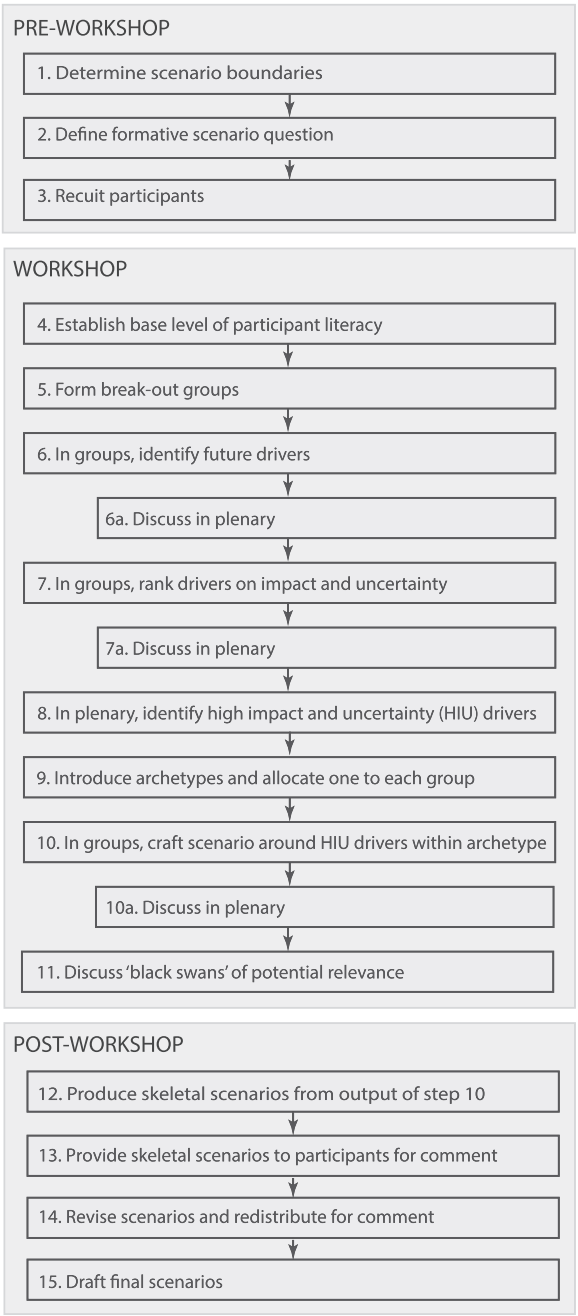
PRE-WORKSHOP
1. Determine scenario boundaries
2. Define formative scenario question
3. Recuit participants
WORKSHOP
4. Establish base level of participant literacy
5. Form break-out groups
6. In groups, identify future drivers
6a. Discuss in plenary
7. In groups, rank drivers on impact and uncertainty
7a. Discuss in plenary
8. In plenary, identify high impact and uncertainty (HIU) drivers
9. Introduce archetypes and allocate one to each group
10. In groups, craft scenario around HIU drivers within archetype
10a. Discuss in plenary
11. Discuss 'black swans' of potential relevance
POST-WORKSHOP
12. Produce skeletal scenarios from output of step 10
13. Provide skeletal scenarios to participants for comment
14. Revise scenarios and redistribute for comment
15. Draft final scenarios

Fig. 1. Summary of the scenario method.

process whereby participants must turn to their imagination to make sense of available information and newly assumed values.

A myriad of future archetype frameworks have been proposed in the literature (Hunt et al., 2012). We chose the Mānoa School model for two reasons. It has stood the test of time (Dator, 1986); and, unlike much of the literature, it is not based on a two-by-two uncertainty matrix approach that, in the face of diverse interests, runs the risk of being overly reductionist (Boschetti, Price, & Walker, 2016).

Our scenario process, summarized in Fig. 1, had three distinct stages: pre-workshop preparation, the workshop, and post-workshop iterations.

2.1. Pre-workshop preparation

The pre-workshop stage began with decisions around the scenario boundaries (Step 1). This included deciding the level of

quantitative input, the time-horizon, geographical scope and scale, and whether the scenarios would be future histories or snapshots in time.

When deciding whether to include quantitative elements, we considered the type of situation, the desired outcome, the available data and their inherent levels of uncertainty (van Notten, Rotmans, van Asselt, & Rothman, 2003). The aim of the project was broad. It sought to understand firstly, what may drive the development of geoengineering globally, in what ways it might occur, and Australia's place in it; and secondly to begin a conversation on geoengineering in Australia. So, quantitative data, which are generally required if the project explores technical scenarios, were not essential for this exercise.

For the choice of time-horizon we considered key decision points, durations of and delays in relevant potential environmental and social impacts, and how far into the future resources need to be committed (Armstrong, 1978; Linneman & Kennell, 1977). Based on an analysis of climate models (IPCC, 2013), we opted for a time-horizon of 2050 as a point when 2 °C of global surface warming is conceivable and the use of negative emissions technologies is widely anticipated.

Scope and scale are intimately linked and are often determined by the subject matter and the jurisdiction of relevant decision-makers. As the purpose of our scenario exercise was wide-ranging, we took a broad approach, opting not to exclude any climate relevant technologies. Had we wanted to target specific issues of geoengineering or climate change policy, we could have opted for a narrower scope; for example, had we been interested in how the future of solar geoengineering might impact on investment into coastal infrastructure, the scope could have been narrowed by technology and geographic location. To situate Australia within the global geoengineering context, we chose to develop multi-scale scenarios: Australia as a subsystem of the world. When the local environment is heavily influenced by the global environment, multi-scale scenarios are a way to link scenarios across geographic scales (Zurek & Henrichs, 2007).

Scenarios can be presented as a story of the future from now until then, or as a snapshot of a future situation. Either approach can be useful for specific purposes, however we chose the former because this "approach is generally preferred by those engaged in policy analysis and choosing strategy, because it provides cause and effect information" (Becker, 1983, p. 96).

Determining the scenario boundaries helps to focus the question that will define the scenarios (Step 2) by making explicit some of the foundational assumptions. The question frames what can and cannot be considered by the participants within the scenario exercise. In this case the question was crafted carefully around the ultimate purpose of the exercise. To reflect the broad nature of our purpose, the question was framed as: "what are the drivers and uncertainties that might affect how the world/Australia manages geoengineering in 2050?".

The scenario question also helps to determine the types of participants to include (Step 3). The right mix of participants is an essential basis for maximizing the credibility and legitimacy of the scenarios (Patel, Kok, & Rothman, 2007). The participant selection process seeks to bring together different types of values and knowledge (Wilkinson & Eidinow, 2008) from across different sectors of society, including experiential and authoritative specialist knowledge from the areas relevant to the scenario question (Richards, Carter, & Sherlock, 2004). There is no perfect number of participants, and there is a trade-off between inclusiveness and productive group dynamics (Richards et al., 2004). However, all participants must indicate a willingness to detach their contributions to the process from their own agendas and interests (Volkery, Ribeiro, Henrichs, & Hoogeveen, 2008).

We recruited a heterogeneous group of twenty stakeholders and experts relevant to climate change policy from academia, business, civil society, and government. Participants had scientific or experiential knowledge in areas covering engineering, marine and earth sciences, energy, water, ecosystems, Australian politics, environmental law, climate negotiations, carbon markets, finance, international relations and security. Criteria for expertise were established as currently or recently employed in a senior position within a relevant government, non-government, or business organisation; having published relevant articles in a peer-reviewed journal or relevant reports with a reputable organisation; or formally engaged as a representative of a relevant sector of civil society (for example a youth advocate or indigenous outreach officer). Fig. 2 shows the participant distribution by gender, sector and discipline.

2.2. The workshop

The workshop began in a plenary session as a means of establishing a shared base-level of literacy in the subject under discussion (Step 4). This was an opportunity to dispel misconceptions or misunderstandings within the group and to appreciate the mutual

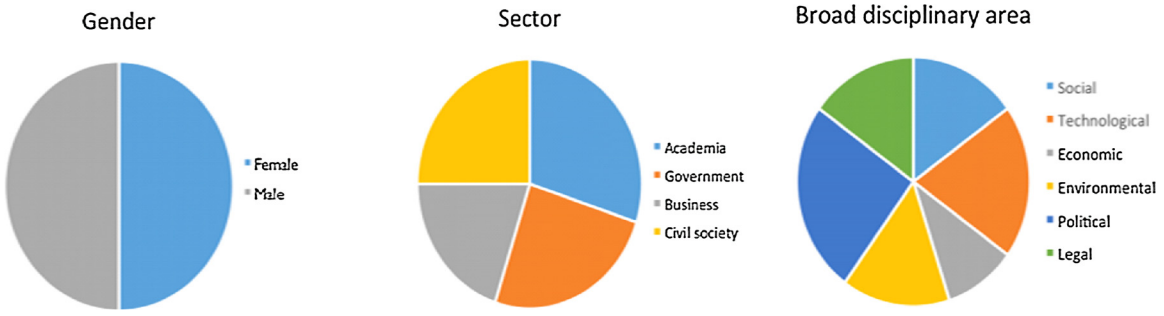

Fig. 2. Distribution of gender, sectors and disciplines within the group of participants.

relevance of participants' expertise. At this stage, it was important not to embed any particular framing of key geoengineering issues, which might risk closing down the discussion (Bellamy, Chilvers, Vaughan, & Lenton, 2012). We chose to begin the workshop with a question-and-answer session on geoengineering in which the participants could ask questions of experts and of each other.

The participants were then divided into four subgroups (Step 5) (these were socially engineered to ensure heterogeneity). The subgroups were posed the scenario question and given time to discuss and list key driving forces and uncertainties that were relevant to the question (Step 6). They were directed to consider all types of unknowns, uncertainties, forcings, drivers, trends, events, factors and actors, whether social, cultural, technological, economic, environmental, political or legal. These were then discussed in plenary (Step 6a). The subgroups were asked to rank the drivers in terms of impact and level of uncertainty (Step 7). The conclusions and rationales of each subgroup were discussed in plenary (Step 7a), where the high-impact/high-uncertainty drivers were identified and further discussed (Step 8). The key drivers identified were:

- global geopolitical stability,
- cultural acceptance of geoengineering,
- social and political pressure to act on climate change, and
- the role of private technology and financial interests in acting on climate change and in developing geoengineering technologies.

The activities in Steps 6 and 7 were repeated focusing this time on the drivers and uncertainties that might affect how Australia manages climate change in 2050. Participants were instructed to consider the outcomes from the previous activity but not be restricted by them. The outcome of the discussion was six high-impact/high-uncertainty drivers:

- the effectiveness/longevity of the Paris Agreement,
- generational change (the potential for a new cultural paradigm),
- climate change impacts and our ability to adapt,
- the potential for major socio-economic or 'ecosystem' events,
- national security views of climate change, and
- the role of the media in Australia.

At this point, the scenario archetypes were introduced and described referencing Table 1 (Step 9). Each subgroup was allocated one future archetype and asked to craft a scenario around the high-impact/high-uncertainty drivers identified in the previous step, but also conforming to the allocated archetype (Step 10). The six drivers were displayed on a screen as guides for the groups while they crafted their scenarios around the archetypes.

The scenarios were described and discussed in plenary, focusing on internal consistency and credibility (Step 10a). Each of the plenary discussions (Steps 6a, 7a, and 10a in Fig. 1) proved important: although the smaller groups were effective at seeding and feeding creativity and imagination, it was only through the combined expertise of the entire group that ideas were vetted for scientific integrity, credibility and consistency. This step resulted in five scenarios because the 'Collapse', 'Discipline' and 'Transform' groups each crafted one scenario, whereas the 'Growth' group presented two different variants as potential outcomes from the same parameter settings. The discussion highlighted internal inconsistencies within some of the scenarios; these were addressed through negotiation in plenary.

Before closing, participants were asked to discuss in plenary the relevance of any potential 'black swan' (Taleb, 2007) events, and to indicate whether these arose during discussions (Step 11). Black swan events are unforeseen disruptive events that are explainable with hindsight. The purpose of this step was not to feed into the scenarios directly but to raise awareness of such issues, which could influence comments during the post-workshop stage.

2.3. Post-workshop iterations

After the workshop, we produced skeletal scenarios that represented what was discussed in the final moments of the workshop (Step 12). Participants were provided the skeletal scenarios by email and were given adequate time to discuss them 'virtually', focusing on the credibility and internal consistency of the scenarios and providing detail around potential turning points (Step 13). The purpose of this post-workshop step was twofold. It allowed participants time to 'digest' the workshop process and findings so as to provide more reflective insight and feedback. It also neutralized the effects of any social dynamics established during the workshop that may have been skewing the collective outcome. The comments from this first round were incorporated into the scenarios. These were then revised and resubmitted to the group for a second round of review, this time focusing on the scenarios as a collective (Step 14). Participants' comments informed the final revision of the scenarios (Step 15). During this second round of feedback one of the Growth scenario variants was found to be internally inconsistent and eliminated. The revised four scenarios—'Corporatocracy', 'The Purge', '1984′, and 'Spaceship Earth'—were finalized based on the feedback.

3. Results

Precis of the four scenarios are provided here.

3.1. Corporatocracy (growth)

In a growing and continuously developing global economy, states have gradually transitioned from the twentieth century 'welfarist' model to a largely privatized economy. Corporates hold strong influence over policies and politics. Cultures are increasingly consumerist and technology development is continually accelerating. The Paris Agreement has transformed climate change from a long-term into a short-term threat to corporations, driving directors and boards to consider climate change in their company decision-making. A defining technological development is the gradual introduction of a hydrogen economy based on gasification of biomass grown in fertilized oceans. As a result of this, carbon concentrations have begun to stabilize, but the transition has been slow and climate sensitivity has been high; a two-degree temperature increase was not avoided. Elevated temperatures and climate impacts have impacted on the agricultural sector's ability to feed the growing global population. Agricultural conglomerates, frustrated by the focus on carbon emissions rather than actual climate impacts, lobby for the Paris Agreement to be amended to refer only to temperature targets. This amendment justifies the deployment of solar geoengineering. However, in this world where money is power, inequality rises both within nations and between them. Grassroots campaigns pursue agendas that reject a society controlled by undemocratic profit-seeking. An opportune window appears for campaigners as solar shields begin to fail.

The Australian population readily accepts the Corporatocracy. The ability of Australian corporations to adopt low-carbon ways dictates how powerful Australia remains and how directly involved Australian corporations (by extension Australia overall) are in setting global reform agendas.

3.2. The Purge (collapse)

A culture of short-termism impacts on governments' and corporations' abilities to manage complex longer-term risks. The Paris Agreement fails to catalyze emissions reductions. Temperatures soar. A series of extreme weather events creates recessionary conditions. The stalling of economic growth causes corporate defaults triggering global economic collapse. At the same time, conflicts over natural resources become frequent and violent. Food supply chains fail, and disease becomes widespread. Political tensions are high. Populations are weakened and significantly reduced. There is no capital available for innovation. Due to economic collapse greenhouse gas emissions plummet, but atmospheric concentrations are already high. The backbone of inter-state diplomacy remains but nations turn inwards. Many succumb to authoritarian regimes. Countries with political systems that favor longer-term planning weather the crisis best. In the United States, certain states (i.e. California and Texas) declare independence. Despair and collapse is unevenly distributed; urban populations are the least resilient. Rural areas are where the world begins again as small agricultural ventures appear across landscapes.

Australia too is frustrated by short-termism. Utilities, infrastructure and livelihoods are destroyed by erratic heatwaves and prolonged droughts that are broken only by intense storms and floods. Human impacts become catastrophic, and financial costs unsurmountable. Insurance companies collapse. Governments cannot afford to bail them out. Agricultural and mining industries fold. Once prime agricultural land in the north is abandoned. Centralized energy systems are dysfunctional and town water is polluted and unpotable. Southern Australia, still viable for cropping, is where small farms begin to appear and link. The government, weak and decentralized, has limited influence over semi-autonomous colonies, powered by decentralized grids, rebuilding from the ground up.

3.3. 1984 (discipline)

Frequent damaging weather events exacerbate living costs. Insurance premiums sky-rocket, bringing climate action into political focus. The world begins transitioning away from emissions-intensive commodities, creating stranded assets and threatening the viability of investment funds. Governments intervene but have limited capacities to stimulate economies. By 2050, national economies are characterized by low growth, high unemployment and record debt. Atmospheric carbon concentrations begin to stabilize, but climate sensitivity is high. Governments join with banks and insurance companies to co-fund innovative climate adaptation efforts that are supported by communities for job creation (i.e. artificial reefs conserve marine ecosystems while stimulating fishing and tourism industries). However, severe weather events are still frequent, and adaptation is insufficient. Geoengineering is accepted as a last hope. Rich countries deploy SRM technologies 'rebadged' (like the artificial reefs) as temporary conservation measures and economic growth platforms. The United Nations (UN) oversees deployment. Globally, citizens unite in the hope that SRM will work. Dissenting voices are silenced. Geoengineering deployment also heightens the focus on rapid carbon reductions. Top-down measures, such as emissions budgets, drive the proliferation of CDR technologies. Despite its perceived success, this totalitarian governance approach is vulnerable: black markets exploit carbon accounting loopholes, and protest political movements challenge the sustainability of the 'command economy'.

As its export products lose value, Australia's economy fluctuates between low growth and recession. Frequent extreme weather events raise living costs. As the Murdoch empire collapses, a new phase in Australian media begins and support for climate action is strong. The government enacts ambitious policies. The Australian 'clean tech' economy finds its niche in renewable energy and energy efficiency, and experiments with genetically engineered crops to alleviate food prices. Australia joins with other nations deploying SRM.

3.4. Spaceship Earth (transform)

Technology permeates all. Everything is available online. Artificial intelligence is embedded everywhere. The human/non-human

boundary is blurred. In developed nations, humans move toward a more cyborg-like existence: naturally problem-solving efficiently, making 'wise' decisions, but also becoming indifferent to Nature. The concepts of 'family' and 'work' have changed. As women's education levels have risen, the global population has peaked and now declines. By 2050 greenhouse gas emissions are near-zero. The Paris Agreement is no longer needed. Although globalization has continued, a societal appreciation of collective global security has developed. Scientific advancements are tuned into complexity theory. However, Man's relationship with the Earth is now envisioned as symbiotic rather than harmonious. The Sustainable Development Goals are thus 'retuned' and achieved. CDR becomes widespread. Energy is abundant due to the use of renewable sources and carbon capture and storage. Agricultural staples are engineered to absorb more carbon, and the sucrose is converted to edible protein. To maintain required growing conditions, SRM is rolled out. Geoengineering becomes a tool for achieving a controlled climate to grow 'new' foods. A treaty strictly regulates any form of SRM, including independent inspection of facilities as part of a verification process. CDR is far less regulated.

Australia, with its technological advancement and early adoption of information technology, takes on a soft global leadership role. Climate vulnerability drives Australia's engagement in mitigation, adaptation and climate intervention, capitalizing on abundant wind and solar energy resources, and vast availability of land and territorial seas for CDR. Australia continues to value its US alliance above all others and therefore hitches its star to US geoengineering initiatives as part of a balancing effort against a more powerful China.

4. Analysis

4.1. Insights from the scenarios

To validate our pre-workshop preparation, we compare the findings from Steps 6 and 6a, where the participants identified the key determinants of global climate change management in 2050, with the existing literature. In their meta-analysis, Talberg et al. (2018) determined that four scenario elements were common to a majority of the geoengineering exploratory and participatory scenarios processes. We compared the global drivers from our scenario exercise to those identified in Talberg et al. (2018) (Table 2). We found strong parallels between the two sets. However, we note that the scope of scenario exercises in the literature was narrower than ours, focusing solely on geoengineering, and often on SRM specifically. Our wider focus on climate change resulted in more broadly defined variables. This could also explain why our group did not identify the controllability of geoengineering technologies as a key issue. However, our wider focus did lead to the identification of an additional key variable: the role of the private sector in financing and technology development.

To gain insight from our scenarios, we looked for commonalities and differences in how geoengineering was included. Our scenario method was designed to create scenarios that diverge on fundamental elements making commonalities uncommon. Nonetheless, the analysis uncovered some key overlaps and divergences that help to advance discussions on geoengineering governance, particularly in the areas of climate impacts, the risk of unilateral SRM deployment, the framing of geoengineering, and Australia's role.

4.1.1. Climate impacts

In three of the four scenarios, extreme weather events and other climate impacts become devastating. In the Corporatocracy scenario, despite market-based efforts to reduce emissions, high climate-sensitivity and delayed climate responses result in elevated temperatures and in weather events that threaten food security. In The Purge scenario, short-termism leads to a climate crisis and subsequent economic crisis. In the 1984 scenario, rigid climate policies and decarbonization efforts prove inadequate, again because climate sensitivity is found to be high. The exception is the Spaceship Earth scenario.

Yet a common feature of all four scenarios is an eventual downward trajectory of greenhouse gas emissions. In the Corporatocracy scenario, emissions reductions occur as the world transitions to a hydrogen-based economy, but the process is slow and is not

Table 2
Comparison of key variables identified in workshop and those from Talberg et al. (2018).

Variables identified in Talberg et al. (2018)	Variables identified in the workshop	Comparison
Degree of global coordination on climate change governance	Global geopolitical stability	Talberg et al. (2018) variable is more narrowly defined
Degree of public acceptability of geoengineering	Cultural acceptance of geoengineering	Talberg et al. (2018) variable is more narrowly defined—public acceptability derives from cultural values
Degree of controllability of geoengineering technologies		No equivalence
Degree of climate sensitivity (severity of climate change impacts)	Social and political pressure to act on climate change	Talberg et al. (2018) variable is more narrowly defined—climate sensitivity or climate impacts contribute to pressure to act
	The role of private technology and financial interests in acting on climate change and in developing geoengineering technologies	No equivalence

reflected in carbon concentrations immediately. In The Purge scenario, emissions plummet as industry sectors fail, but this comes after what is assumed to be a steep upward trajectory in emissions. In the 1984 scenario, a downturn in emissions is also due to a contracting economy but is complemented by strong climate policies. In the Spaceship Earth scenario, low-carbon technology, CDR, and other climate-relevant technologies become widespread early, bringing emissions under control.

Our participants thus struggled to envisage a future in which the upward trajectory in emissions of the last 150 years continues beyond 2050. Yet they also anticipated—except under conditions of accelerated technology development and adoption—that climate change impacts will become matters of global relevance and will have defining roles in shaping the world in 2050. The most envisaged outcome was therefore that global emissions would peak in the first half of this century, but that dangerous climate change would not be avoided.

4.1.2. The risk of unilateral deployment

Geoengineering, both SRM and CDR, is deployed in three of the four scenarios. This is unsurprising, given the deliberate focus on geoengineering in Step 4 of the scenario process (Fig. 1). The participants were thus 'primed' to consider geoengineering as an option to manage climate change. The one scenario that did not include geoengineering was The Purge, which describes complete mismanagement of climate change. Therefore, all scenarios in which climate change was managed to some level of effectiveness included geoengineering.

The key point, however, is that in all three instances, SRM was rolled out under some form of UN-based governance. In the Corporatocracy scenario, the Paris Agreement is amended for that purpose. In the 1984 scenario, the UN (or some equivalent body) oversees deployment. In the Spaceship Earth scenario, a new treaty is negotiated building on existing multilateral agreements. Whereas much of the geoengineering research literature is concerned with the risk of unilateral geoengineering deployment (see for example Barrett, 2008, or Weitzman, 2015) and the prospect of deployment without adequate governance, the participants in our workshop judged this option as unlikely. Interestingly, in only one scenario (Corporatocracy) was geoengineering governance linked to climate change governance, such as through the United Nations Framework Convention on Climate Change.

4.1.3. Framing geoengineering

There is no consensus on the definition of geoengineering or its coverage (Boucher et al., 2014) and there is some apprehension towards providing a firm definition (CBD COP, 2010). Our scenario exercise suggests two considerations on the definition and framing of geoengineering. Firstly, for governance purposes, it may not be useful to combine CDR and SRM within the same definition. Although CDR and SRM were introduced under the one geoengineering umbrella and discussed together in Step 4, the participants ultimately considered CDR and SRM independently and as having different factors or drivers. In the Corporatocracy scenario, CDR is adopted as part of a climate mitigation strategy early and SRM is considered only after mitigation proves insufficient. In the 1984 scenario, SRM is rolled out as a temporary strategy with CDR implemented to ensure that atmospheric carbon concentrations are reduced rapidly. In the Spaceship Earth scenario, SRM is strictly regulated whereas CDR is widespread and comparatively unregulated.

Secondly, each deployment of geoengineering is justified in different ways. The Intergovernmental Panel on Climate Change, the scientific body that advises international policymakers on climate risks and options, has attempted to classify geoengineering as a separate category to climate mitigation and adaptation. However, in the Corporatocracy scenario, the form of geoengineering deployed is best characterized as a form of climate mitigation strategy: it is deployed within the framing of Paris Agreement and ocean fertilization is used specifically to produce biomass for a hydrogen economy. In the 1984 scenario, solar geoengineering is deployed as a temporary conservation measure overseen by the UN, which can be seen as a form of adaptation strategy because its primary focus is reducing vulnerability. Finally, in the Spaceship Earth scenario, climate change is already being effectively managed when solar geoengineering is deployed. The use of SRM can be characterized as climate optimization. These different framings occur in different paradigms, as outcomes of different worldviews, and to achieve different goals. Whether geoengineering is legitimized as climate mitigation, adaptation or optimization can affect its relevance and how it is governed (Buck, 2013; Corner & Pidgeon, 2014).

4.1.4. Australia's role

The six Australian drivers identified during our workshop differed markedly from the four global drivers. This validates our multi-scale approach to the scenario development. A common feature to all four scenarios is that Australia stands to benefit from an early transition away from emissions-intensive climate-exposed exports and towards the 'clean tech' sector. Another aspect common to all but one scenario (Corporatocracy) is that Australia's vulnerability to climate change is a key factor, suggesting that increased focus on adaptation is warranted. Finally, across the four scenarios Australia's role can be characterized as passive; Australia was generally envisaged as a geoengineering 'policy taker' globally.

The Australian government currently has no firm policy position on geoengineering and Australia has contributed minimally to geoengineering policy discussions and research (Talberg et al., 2017). As a result, there is limited scholarship on how geoengineering might impact on the Australian environment. The impacts of geoengineering on the Southern Hemisphere are under-researched and uncertain, yet the remoteness and key features of the Australian landscape reveal potential opportunities for geoengineering field testing. Together these arguments suggest that Australia would be well placed and prudent to embrace an economic transition to low-carbon energy and to adopt early an active stance in geoengineering deliberations and research.

4.2. Reflections on the process

An important aspect of the scenario development process was shared learning. The iterative process, entailing lengthy and reflective discussions helped to evolve the problem and expose interlinkages between issues. The involvement of diverse participants from all sectors of society was not designed to negotiate consensus on issues but to reveal dissimilar understandings of the problems, to identify overlaps and gaps, and to expose new approaches to managing the future.

The process of shared learning can be traced by the journey of ideas throughout the workshop. If the final four scenarios are considered as the outcomes of the learning process, we can compare the various outcomes from previous steps to those final scenarios to trace the evolution of ideas.

4.2.1. Shared learning

We compare first the variables identified in Step 6 with the key features of the final four scenarios. The first variable was geopolitical stability. The only scenario without geopolitical stability was The Purge scenario, yet climate change is managed in markedly different ways in each of the other three scenarios. Geopolitical stability is thus seen less as an uncertainty and more as a prerequisite for climate change management, and therefore a fundamental assumption upon which any future geoengineering deployment must be based. However, here we must qualify this conclusion (and all our analysis). Although the archetype scenario-construction approach is based on the scholarship of Dator (2009) who "determined that all of the billions of images of the future that exist are actually specific manifestations of one of four generic alternative futures" (Dator et al., 2015, p. 136), there is still an infinite number of alternative futures within each of those archetype categories. Our findings are relevant only insomuch as they portray the views and ideas of relevant and expert individuals that have undergone a process of learning and negotiation following a rigorous and defendable process.

The second variable identified in Step 6 was cultural acceptance of geoengineering. Within the scenarios, cultural acceptance of geoengineering, was a factor of the broader paradigm and the framing of geoengineering as a climate policy option rather than a determinant. The third variable, social and political pressure to act on climate change, was exerted in different ways in each scenario. Whereas pressure in the Corporatocracy scenario stemmed specifically from agricultural groups and the threat of food insecurity, in the 1984 scenario, it stemmed from the public and increased cost of living due to extreme weather events. However, the social and political pressure variable did not feature in either of the other two scenarios. This suggests that the influence of this variable is only relevant through its interconnection with other variables. Finally, the role of private technology and financial interests in acting on climate change and in developing geoengineering technologies was a differentiating feature of the scenarios. It was mediated by other factors but became directly relevant in the outcomes of the scenarios.

To summarize, although the four variables mapped consistently to those identified in the literature, through the process of shared learning those variables evolved. Geopolitical stability was treated as a necessary condition of effective climate change management, rather than a mere determinant. Cultural acceptance of geoengineering, the pressure to act on climate change and the role of the private sector, were each treated as variables that were determined by the cultural paradigm and external pressures, all of which ultimately influenced the framing of geoengineering.

Analysis of the evolution of the six Australian drivers found that many ultimately became redundant. Whereas participants had considered these elements as crucial in the early stages of the process, through negotiation, many elements became irrelevant. As examples: only one scenario included the Australian media as influential in climate change management; in no scenario was Australia's national security views of climate change relevant; and the longevity of the Paris Agreement was an outcome rather than a factor. However, climate change impacts and Australia's resilience were considered key factors in the final scenarios. The learning process also revealed that Australia's ability to rapidly decarbonize and engage with the 'clean tech' industry was the most crucial determinant and had been overseen in the early stages of the workshop.

Finally, the post-workshop iterative process progressed the scenarios considerably. A defining element of this was in the second iteration when five scenarios became four. During the workshop, the 'Growth' breakout group determined that two variants were equally viable. In Variant 1, climate change was eventually integrated into all business decision-making up to the corporate board level. In Variant 2, directors of large corporations continued to resist such efforts. Both variants were expanded, revised and refined. However, in the second iteration of the post-workshop stage, Variant 2 was considered internally inconsistent and implausible. It was thus eliminated. Through a shared learning process, the participants determined that by 2050, in a world where economic growth is the defining paradigm, it was inconceivable for corporations to disregard climate change in their business planning. Here, further research, for example through targeted participant interviews, could help to pinpoint the conflicting dimensions and relevant factors that led to this conclusion.

4.2.2. Limitations

Reflection on the scenario process must include consideration of the study's limitations. This is to contextualize the findings but also to contribute to the academic process by which scenario-based research can be grown and improved with scientific integrity. An important reminder is that scenario-based research provides insights that are avenues for further study or for cautious policy-making, but they do not provide answers. The future is unknowable.

A second point is that this process is best suited to the early stages of public policy development where it is still possible to debate the broader issues, raise awareness, increase stakeholder engagement, introduce new mind-sets, and reframe issues (Volkery & Ribeiro, 2009). Scenario-based methods that support more immediate and direct decision-making are usually not based on archetypes methods and have shorter time-horizons. Our method is ideally suited to contested and emerging long-term issues, such as

geoengineering. A different method will be more appropriate for more immediate policy issues.

A third point is that our scenario process made a series of compromises to balance methodological rigor with the time constraints of those most likely to be involved in these types of activities. Informal feedback from our workshop participants suggested that to adequately explore the contested issues around geoengineering two days of deliberation would have been welcome. In particular, many participants commented that Step 10, in which subgroups crafted their scenarios around each archetype, proved challenging and warranted extra time to resolve contested views and to integrate previous findings. Yet to secure attendance of just twenty relevant high-profile and expert participants, more than one hundred individual invitations were extended. The main reason for rejection was the considerable time commitment required. As such, a one-day workshop is an appropriate compromise to ensure that the right participants can be attracted without over-sacrificing the time needed for profound discussion.

A compromise may also be necessary regarding the range and diversity of participants included in the workshop. It may not always be practical, affordable or possible, to include all relevant stakeholders. Our workshop, for example did not have a representative from local government, an urban planner, or a health expert due to circumstances beyond our control. A related issue is group dynamics. Certain personalities may dominate discussions, especially when a group includes several thought leaders. This can be minimized through attentive and close facilitation of the workshop but cannot be eliminated.

The post-workshop iterations are one way to neutralize the effects of individual personalities. However, these too pose limitations. The two post-workshop iterative rounds from our scenario exercise were valuable but challenging. Some respondents were concerned that in the two weeks between contact, their memories of the discussions had faded. Some individual participants also did not feel comfortable engaging in a full group email discussion when their views conflicted with those of other participants. As one way to resolve this issue, and to improve the analysis of the learning process, we suggest targeted follow-up interviews with key participants.

5. Discussion

There is an argument that the mere discussion of (or research into) geoengineering normalizes the concept and creates a ‘slippery slope’ that sets the future on an unavoidable trajectory (Cairns, 2014; Hamilton, 2013; Jamieson, 1996; Stilgoe, Watson, & Kuo, 2013). Quoting Churchill, Hamilton (2014) places geoengineering in the realm of “…secrets too mysterious for man in his present state to know; secrets which once penetrated may be fatal to human happiness and glory” (Churchill, 1937). The other side of that argument acknowledges that geoengineering is, for better or worse, being explored. If the inquiry is not opened to a broad audience in an inclusive and transparent manner, it is likely to be restricted to a small contingent of curious scientists that alone will struggle to adequately represent the values and ideals of “human happiness and glory”. Increasing the number and types of discussions around geoengineering, the participants in those discussions and the questions being asked, can only improve the design of governance that evolves. Scenarios are one way of having these discussions in a manner that can inform policy and planning (Schwartz, 1991).

Exploratory scenario methods have been used to inform Australian public policy development, in for example climate change adaptation (Rickards, Wiseman, Edwards, & Biggs, 2014), biodiversity management (Bohensky et al., 2011), irrigation (PIRVic, 2006) and energy (Energy Futures Forum, 2006). Generally, scenario exercises over public policy questions are reported as successful—at least from the perspectives of participants (Volkery & Ribeiro, 2009). They have been shown to increase awareness, improve strategic communication skills, individual learning, policy-learning, and reconsideration of policy assumptions (Chermack, Lynham, & van der Merwe, 2006; European Environment Agency, 2009), and it has been suggested that they may help policy makers to think in the longer-term (Rickards et al., 2014).

However, a critique of these types of scenario exercises is that they tend to be discreet projects that happen in an “ad-hoc and isolated manner” (Volkery & Ribeiro, 2009) with limited integration with the broader decision-making environment. To address this, more systemic approaches to foresight have been established for public policy development. Examples have been seen in the United Kingdom, Singapore, the Netherlands, and Finland where foresight agencies have been established (Habegger, 2010; Volkery & Ribeiro, 2009). These have led to stronger networks between government agencies and to other societal sectors and have produced broad ranges of alternative policy options (Habegger, 2010). The Australian Federal government too established such an agency in 1986—the Australian Commission for the Future. However, it was not highly successful and ended in 1998 because it was “under-equipped and under-designed” (Slaughter, 1999, p. 93); processes lacked formal and methodological rigor, and staff were unskilled for futures work.

Geoengineering could present an appropriate policy issue to re-explore the inclusion of structured and systemic foresight methods in Australian government processes. To date, most governments have not been active in geoengineering discussions, preferring to ‘wait and see’, and Australia has been largely absent from any geoengineering debates (Talberg et al., 2017). Scenario exercises such as ours, but driven through public initiatives, would allow Australian governments to engage in geoengineering debates without predetermining policy outcomes or being accused of ‘picking winners’.

Our scenario process began an open and unbiased conversation on geoengineering between Australian academics, regulators, businesspeople and civil society, where there has been little such discussion to date. That conversation included the perspectives from many different experiences and backgrounds. Due to the nature of the scenario exercise, all participants and their perspectives held equal standing. The learning that took place was iterative and transformational and focused on the future while integrating lessons from the past. The exercise also brought a multiscale dimension to the conversation on geoengineering. It allowed the participants to identify and understand those elements of the future that cannot be changed but must be responded to, while highlighting those elements that are not predetermined and can be altered. This opened up the range of policy options, for example looking at different ways of framing geoengineering in the climate debate. Where it made clear that potentially undesirable outcomes could be averted with simple early actions, the exercise helped to uncover no-regrets policies.

Mostly, scenario exercises designed for public policy tend to use the two-axis scenario method in which four scenario quadrants are formed based on the combinations of opposing extremes from two key variables—generally, high-impact and high-uncertainty variables. For this method to work, some level of consensus is required on the values and definition of the two variables that form the axes (van' t Klooster & van Asselt, 2006). Consensus is hard to achieve in government exercises because of the disparate views, interests and backgrounds of the participants that stem from different sectors or departments (Parson et al., 2007). Research also suggests that the two-axis method tends to exclude surprising or disruptive events (Postma & Liebl, 2005). Our method, partly founded on the four archetypes of Dator (2009), instead urged the participants to embrace 'uncomfortable' futures (Ramírez & Ravetz, 2011).

Scenario planning, or "forward engagement" (Fuerth, 2009, p. 61), teams could be established within or across government departments to allow for policy problems such as geoengineering to be approached systemically with a view to sustainable future-oriented solutions. Foresight teams exist in Australian government agencies, but these are generally restricted to portfolios with oversight on issues of national security (James, 2001); they are rarely seen in portfolios covering environment, health, immigration, innovation or education. Geoengineering, for example, is an issue that straddles many policy domains. The Australian Commission for the Future sat externally to the portfolios, which may have contributed to its lack of buy-in from department policy-makers. Instead, 'forward engagement' teams might sit most appropriately under the remit of central agencies such as the Department of Prime Minister and Cabinet or the state-level Departments of Premier and Cabinet, where they would benefit from relationships with all the line agencies (Habegger, 2010). Alternatively, a parliamentary body could be established, similar to the Australian Parliamentary Budget Office or the Research Branch of the Parliamentary Library, that would run scenario exercises in the interests of parliament rather than the government, thus more readily permitting scenarios that challenge political priorities (Slaughter, 1999).

On an issue such as geoengineering, the relevant departments with which 'forward engagement' teams would liaise would include those overseeing foreign affairs, defense, health, innovation, infrastructure, and the environment. External stakeholders from special interest groups and business would also be invited to participate in scenarios exercises, creating a "safe space" (Volkery & Ribeiro, 2009) to discuss and make sense of problems (Weick, Sutcliffe, & Obstfeld, 2005; Wright, 2005).

6. Conclusion

Although scenarios are foundational elements in much of the geoengineering scholarship, they are rarely exploratory and participatory in nature. There is only one other geoengineering family of scenarios built from a participatory process, such as ours, in the peer-reviewed literature (Bellamy & Healey, 2018). This limits the extent to which scenarios, as a practice, can evolve and develop into a robust and effective strategies or aids for geoengineering decision-making. It is hoped that our study provides a stimulus for further such research.

Just as the challenges to sustainability are increasingly complex and far-reaching, so must the search for solutions become more imaginative, bold and sophisticated. Towards that end, our scenario construction process is a practical method for generating new ideas and knowledge in highly contested policy areas. An important aspect of the scenario development process is creating an 'agora'—"a domain of primary knowledge production, through which people enter the research process and where knowledge […] is embodied in people, processes and projects" (Nowotny, 2003, p. 156). By facilitating shared learning, the process provides a clear pathway within the 'methodological chaos' of scenarios to revisit and challenge accepted norms and framings that underlie discussions of long-term sustainability governance issues. This can be relevant to the policy process in one of two ways. If the process serves to validate previously held theories, it can strengthen confidence about the likely impacts and implications of policy choices and decisions (Rau, Goggins, & Fahy, 2018). If, in contrast, the process introduces new conceptions of the problem area, it can broaden the scope of viable policy options. The scenarios suggested for example that Australia would be prudent to prepare for temperature increases of more than 2 °C; to invest in clean technologies; and to explore early the implications of geoengineering on Australia. However, to take advantage of 'windows of opportunity' (Volkery & Ribeiro, 2009) and to provide useful input into policy and politics of geoengineering in Australia, scenario exercises could be undertaken as ongoing processes integrated into the governance landscape.

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Conflicts of interest

None to declare.

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